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Interpretation of the Results of Doppler Ultrasound Flow Volume Measurements of Infrainguinal Vein Bypasses

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Objectives. *To evaluate a pattern for the interpretation of the results of intraoperative Doppler ultrasound flow volume measurement of infrainguinal vein bypasses.*
Design. *Retrospective analysis of prospective data.*
Materials. *91 consecutively performed infrainguinal non-reversed free vein bypasses.*
Methods. *Using preoperative angiograms, the run-off, which can be expected after the reconstruction, was evaluated by means of a point score. A first measurement of the flow volume was taken after the release of the blood flow and a second after administration of 20 mg Alprostadil into the bypass. From these two results, we calculated an average value, which was set in relation to the run-off score. From this we computed a relative flow, i.e. the flow per open crural vessel = per run-off score unit (quotient: flow/score).*
Results. *The median relative flow of angiographically perfect reconstructions was 86 ml/min. In 14 reconstructions, the control angiogram showed stenoses: median relative flow 59 ml/min, range between 20 and a maximum of 75 ml/min. The practical application of the flow measurement requires a minimum relative flow guideline for stenosis-free reconstructions. A guideline of 80 ml/min would yield a sensitivity of 100% and a specificity of 68%.*
Conclusions. *Measurement of flow volume could be used as a screen, in order to filter out reconstructions, which must be further clarified with an angiogram. A further prospective evaluation of the value of volume flow is needed before any conclusive recommendations can be drawn.*

Keywords: Doppler ultrasound; Duplex; Volume flow; Screening; Bypass; Vein graft.

Introduction

Intraoperative quality assurance is an important component of femoro-distal bypass. Completion angiography is regarded as gold standard, however, intraoperative duplex imaging is also employed. In this paper, we present a pattern for the interpretation of intraoperatively measured flow volume rates.

Patients and Methods

In a retrospective analysis, we analyzed the prospective data ascertained from 91 infrainguinal, autologous, non-reversed vein bypasses performed consecutively (demographic data: Table 1). For the evaluation of the distal run-off, we made use of the 'modified run-off score' (maximum range: 3–0 pts three open and non-stenosed crural arteries: 3 pts; all crural arteries occluded: 0 pts).[1,2]

Before the operation, each patient underwent an angiogram using a swivel-mounted, single-plane Siemens Multistar®. After injection of 60–80 ml of contrast medium, angiographic images of the pelvis and legs were taken using the DSA technique. A control angiography was performed either during the operation after flow measurement or on the first postoperative day. For intraoperative completion angiography we used a Siemens Siremobil Compact SR 110 C-arm.

In order to produce a pattern that would make the interpretation of the flow values measured intraoperatively possible, we consulted pre- and post-surgical angiograms. Post-surgical angiograms were then considered, if they showed pathological results (stenoses), which decreased the flow in the bypass. In these cases, we corrected the run-off score downward with respect to the stenoses. In this way, we evaluated the actual run-off and avoided a distortion of the relationship between run-off and the correlating flow

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Table 1. Demographic data

Sex	
Male	43 (47%)
Female	48 (53%)
Age	
Median	73 (42–93)
Renal failure	
No	67 (74%)
Yes	24 (26%)
Diabetes mellitus	
No	48 (53%)
Yes	43 (47%)
Smoking in the last 10 years	
No	60 (72%)
Yes	31 (34%)
Hypertension	
No	40 (44%)
Yes	51 (56%)
Body mass index	
BMI <20	1 (1%)
BMI 20–26	49 (54%)
BMI >26	41 (45%)
Hyperlipaemia	
No	39 (43%)
Yes	52 (57%)
Pre-operative medication	
Anticoagulation	20 (22%)
Platelet aggregation inhibitor	40 (44%)
Non-steroidal antirheumatic	3 (3%)
Clinical stage before bypass surgery	
Asymptomatic aneurysm	2 (2%)
Intermittent claudication	24 (26%)
Pain at rest	10 (11%)
Necroses	55 (60%)
Proximal bypass anastomosis	
Common femoral artery	46 (51%)
Superficial femoral artery, proximal	6 (6%)
Superficial femoral artery, middle	11 (12%)
Superficial femoral artery, distal	14 (15%)
Popliteal artery, below knee	10 (11%)
Deep femoral artery	4 (4%)
Distal bypass anastomosis	
Popliteal artery, above knee	7 (8%)
Popliteal artery, below knee	30 (33%)
Anterior tibial artery	19 (21%)
Posterior tibial artery	7 (8%)
Peroneal artery	19 (21%)
Tibio-fibular trunk	5 (5%)
Pedal artery	4 (4%)

value. The consideration of post-surgical angiograms was essential to the formulation of the pattern. The application of the pattern in practice is, of course, only practical when based on pre-operative angiograms.

For the intraoperative measurement of the flow volume, we used a Cardio Med TRaCe System CM 2008 instrument (transit time flowmeter) with measuring probes of either 3 or 4 mm, depending upon the diameter of the bypass. The anaesthetic was administered in such a way that, at the beginning of the flow measurement, the systolic blood pressure value lay between 110 and 120 mmHg. The first measurement was taken immediately, after the release of clamps. In order to lower the peripheral vascular resistance, we used a fine cannula to administer 20 μg of Alprostadil distal to the proximal anastomosis in the bypass and performed further measurements for a few minutes and selected the maximum flow. From the initial flow rate and the rate after Alprostadil application, we calculated an average rate. We set the flow rates in relation to the run-off score, by calculating a relative flow, the flow rate per point run-off score.[1]

Statistical methods

Mann–Whitney *U*-test was used to assess significance, regarded as $p<0.05$. For the cutpoint-analysis, we computed specificity and sensitivity and presented them graphically as an ROC curve.

Results

The median angiographic run-off score ($n=91$) was 1 (range: 0.3–3). The median flow rate was 104 ml/min (range: 17–530). The median relative flow was 86 ml/min (range: 30–407). In 14 reconstructions, the control angiogram showed stenoses in the reconstruction area—be it in the distal anastomosis or from remains of valve cusps—which impaired the run-off (Table 2). The relative flow rate for these 14 reconstructions was a median of 59 ml/min (range: 20–75), calculated using the pre-operative angiogram. After correction for the intraoperative angiogram, the relative flow rose to a median of 115 ml/min (range: 90–178). Diagram 1 graphically shows the difference between the relative flow rates of reconstructions with stenoses caused by operation technique ($n=14$) and with primarily stenosis-free reconstructions ($n=77$; 82 ml/min; range 30–407) (Mann–Whitney *U*-test: $U=234$; $z=3.35$; $p=0.0008$).

The 14 bypasses, in which the control angiograms revealed pathological results, had relative flow rates between 20 and 75 ml/min. If all of the reconstructions ($n=33$) with relative flow rates of 75 ml/min or less are considered, then a pathological result was detectable through angiography in 14/33 cases.

The practical application of the flow measurement requires a guideline for a minimum relative flow, which should, at the very least, be reached during the operation. Eighty milliliter per minute is offered as a guideline for the minimum relative flow, below which the intraoperative flow measurement of a freshly performed bypass should not fall. This figure is a handy, practical, relative flow rate between the lower

Table 2. Pathologic findings in the reconstruction area caused by operation technique

Pathologic findings	Pre-operative score	Relative flow (in relation to pre-operative score)	Score corrected downward through error
Proximal anastomosis stenosis	1.4	71	0.7
Distal anastomosis stenosis	0.8	50	0.4
	1.2	29	0.6
	1	75	0.8
	0.8	61	0.5
	1	50	0.5
	1	31	0.5
	1	42	0.5
	1	20	0.3
	1	75	0.5
Stenosis below the distal anastomosis	2.5	63	1.5
Flap remnants	1	63	0.5
	1.5	57	1
	0.7	64	0.4

limit of 75 ml/min (below which stenoses are expected) and the upper limit of 86 ml/min (median relative flow for the stenosis-free total collective). This guideline of 80 ml/min results in a sensitivity of 100% and a specificity of 68%. The sensitivity and specificity of various flow rates are shown in Table 3 and graphically shown as an ROC curve in Fig. 2.

Discussion

Angiography has been established as the standard technique for intraoperative inspection of infra-inguinal bypasses. Duplex ultrasound is an excellent method of bypass surveillance post-operatively.[3–6] The measurement of the flow velocity allows for the detection of stenoses, both intraoperative and during the post-surgical aftercare examination, and is a tool used routinely in daily clinical practice.[5–11]

The Doppler ultrasound measurement of the flow volume in the bypass (ml/min) has so far attained no value for the intraoperative quality control of a freshly performed bypass, even if it is a far easier method to perform than the angiography or a duplex assessment of the flow velocity in the entire bypass.

Previous papers describe changes in the flow volume in the reconstruction zone, both before and after application of vasodilatative substances.[12–14] With *in situ* bypasses, unligated side branches can be detected.[15] Stirnemann *et al.* found that, in order for a reconstruction to remain open, vein bypasses require 10 ml/min minimum flow and PTFE bypasses require 50 ml/min.[16] From a collective of 257 infra-inguinal vein bypasses, Ihlberg *et al.* showed that, with regard to patency and development of stenoses, reconstructions with high intraoperative flow volume measurements have better short- and long-term prognoses than bypasses with a small flow volume.[17] The statements in this paper rely upon median flow volume rates of the total collective or larger subgroups and are to be understood as a general conclusion. To date, conclusions regarding the prognosis of an individual bypass could not be derived through intraoperative determination of the flow volume; therefore, this method cannot be recommended for quality control.[17,18] From an analysis of 172

Fig. 1. Relative flow of primarily stenosis-free reconstructions (median 82 ml/min; $n=77$) and reconstructions with stenoses (median 59 ml/min; $n=14$). Mann–Whitney U-test $p=0.0008$.

Table 3. Sensitivity and specificity of different reference values of the relative flow

Relative flow	Bypass with patholog. results (N)	Sensitivity in %	Specificity in %
120	14	100	56
110	14	100	57
100	14	100	60
90	14	100	63
80	14	100	68
70	11	82	73
60	7	67	77
50	6	64	86
40	3	56	93
30	2	54	99
20	1	52	100

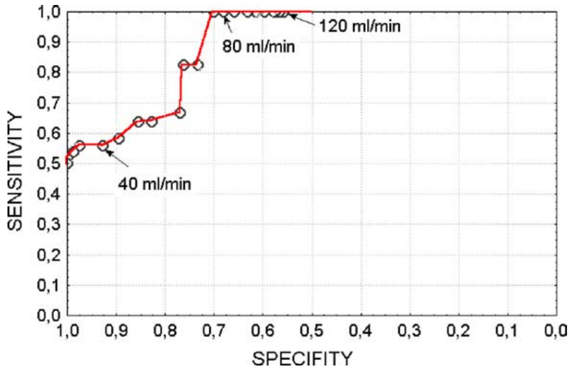

Fig. 2. Receiver operating curve (ROC): With a relative flow of 80 ml/min or more, the sensitivity is 100%.

infrapopliteal reconstructions, Albaeck *et al.* cautiously drew the conclusion that a high 'maximum flow capacity' (volume flow after application of 40 mg papaverine hydrochloride) measured intraoperatively signifies both a good run-off and an adequate bypass.[19] So far, the question of exactly how to define a 'high flow volume' has been left open in the literature.

That the measurement of the flow volume (ml/min) has been unusable for the intraoperative evaluation of the operation result lies in the fact that no criteria for the interpretation of the readings existed. For example, if the surgeon performing a bypass operation measures a flow of 140 ml/min and he has the subjective impression that the value is 'quite good', then he could have a false sense of security. With one open and two closed crural vessels, the value would actually be very good; but it would be disappointing, however, with three open crural vessels. In this case, a problem is to be expected (wrong anastomosis level, anastomosis stenosis, flap remnants, dissection, competition flow from collaterals) and, through a Doppler sonographic scan (peak flow velocity)[7,9–11] and/or an intraoperative angiography, the problem must be either sought or ruled out. The measurement of the flow volume encompasses the hemodynamic of the entire reconstruction zone and merely refers to a possible problem that requires better clarification.

The flow is substantially influenced by the run-off.[1,20] Therefore, it is essential to treat the run-off objectively and to evaluate it quantitatively, so that a guideline for the operation result, derived from the pre-operative angiogram and which will predict the expected intraoperative flow (minimum flow), can be given. Because of its simplicity, its applicability independent of the anastomosis level, as well as its consideration of the retrograde run-off, the 'modified run-off score' makes possible the evaluation of the entire available run-off.[1]

The diameter of the bypass vein and the peripheral resistance also have an influence on the flow.[13,21] Ascer *et al.* showed, that the outflow resistance predicts late patency of infrainguinal bypasses and limb salvage.[22,23] Intraoperatively, the application of vasodilatative substances into the bypass reduces the peripheral resistance and increases the flow. A persistent low flow, despite Alprostadil administration, may be caused by a high persistent outflow resistance due to a progressive distal atherosclerotic disease. On the other hand the persistence of low flow may indicate a technical error, e.g. a false anastomosis level above a stenosis or an anastomosis to the wrong crural vessel. An intraoperative angiography has to clarify, whether a correction or a sequential bypass in order to enlarge the run-off should be performed, or in reconstructions without technical errors closer follow-up evaluations are to be recommended in an attempt to detect a failing graft.

Even if intraoperative angiography is widely regarded as the standard for the quality control of a freshly performed vein bypass, it can merely describe the morphology of the reconstruction. The hemodynamics, however, have not yet been considered.[20] There are a number of authors that deem the Doppler ultrasound a suitable intraoperative control mechanism.[7,10,11,16,19,20,24] In a comparison of angiography and Doppler sonography scans, done through measurement of the peak flow velocity, Papanicolaou *et al.* noted that, with regard to the recognition of results requiring correction, Doppler sonography had greater accuracy and meaningfulness.[7] Stirnemann *et al.* found flow measurement to be a better predictor of outcome than angiography.[16]

In comparison to flow measurement, the intraoperative angiography has further disadvantages, such as higher costs, expenditure of time and greater risk.[20,24] Apart from the possibility of allergic reactions, renal function problems are cited here (24/91 in our series). The Doppler sonographic measurement of the flow volume in freshly performed vein bypasses, when done to detect results requiring correction, is meant for screening, in order to filter out reconstructions that need to be further clarified, by means of Doppler sonography, duplex and/or angiography.

If intraoperative angiography was performed only if the relative flow does not reach 80 ml/min, roughly two-thirds of the intraoperative angiograms could be omitted, because no pathological result is to be expected, with significant cost savings. Before any conclusive recommendations can be drawn on the value of volume flow, a prospective validation with clinical follow-up is necessary.

Appendix A. Calculation Plan and Examples

The relative flow rate of 80 ml/min per crural vessel unit is to be regarded as a quasi-constant ('flow constant'). The practical application of that which has been discussed so far is to be described now by two examples, in order to be able to describe the pattern for the interpretation of the intraoperatively measured flow rates.

Example 1. Femoro-popliteal P-III-bypass with three open and not-stenosized crural arteries:

Run-off score =3.

Minimum expected flow = score × flow constant:

3×80 ml/min=240 ml/min.

The mean of the initial flow and the flow after Alprostadil application should come to at least 240 ml/min. If this rate is reached, then it can be assumed that all is well with the reconstruction result (bypass, anastomoses and distal connection point). If this projected flow rate is not reached, possible errors must be sought out (peak flow velocity, angiography).

Example 2. Femoro-crural bypass on an isolated crural artery segment:

Run-off score =0.2.

Minimum expected flow: 0.2×80 ml/min=16 ml/min.

Conversely, a flow rate that has already been measured can be interpreted as follows: if a flow of 20 ml/min, for example, is measured at the same constellation, then follows the relative flow (=flow/score): 20/0.2=100 ml/min. Thus, the minimum value of 80 ml/min (flow constant) would be reached. If, for example, 10 ml/min is measured, then the relative flow would come to 10/0.2=50 ml/min and be too low, which would call for a further clarification.

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